EnVRonment: Time-Management and Stress Effects from Object Organization in Different Virtual Environments

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Virtual Reality (VR) has the ability to simulate various immersive environments. This ability makes VR a perfect platform for testing various situations in cases where a more complicated experiment setup would have been traditionally required. Stress is a common occurrence in day-to-day lives, and understanding its impact on decision making can give valuable insights into how to minimize this stress. Other research has explored the connection between stress and cognitive ability and has found a link between stress and a negative impact on cognitive abilities. In this research, the connection between color, sounds, stress, and cognitive ability was explored further by recruiting 13 participants and having them complete organizational tasks in three different scenes. They were required to sort three categories of objects into bins. Heart rate and completion time were the two statistics recorded during the experiment, alongside a questionnaire for each participant. All of these aim to measure a participant's stress levels, and the potential connection between cognitive ability. After analyzing the data recorded in the experiment using ANOVA, it was found that the increase in heart rate and completion time for stressful scenes shows a statistically significant association. This means it is likely that stressful scenes in VR induce stress, which in turn negatively impacts one's organizational abilities. Cognitive ability is an important part of day-to-day life, and understanding this negative impact highlights the importance of minimizing stress-inducing factors in our environments.

Additional Key Words and Phrases: Virtual Reality, Stress Testing, Environment Tests, Heart Rate Variability

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1 INTRODUCTION

Virtual reality (VR) has a wide range of applications because of the ability to create various and interactive environments. VR can simulate any environment or circumstances for specific purposes to get the result. Its ability to create complex and dynamic scenarios allows people to set any kind of test they desire, which makes it a valuable tool in research. VR-based assessment systems offer a wide range of benefits across the various domains [24]. As a result, using VR as an assessment tool is a feasible and straightforward way to observe the reaction of people completing specific tasks in designed environments. This makes it an efficient way to analyze results of an environment-based research project.

Since VR can be used to build virtual environments to mimic real-world situations and be an immersive experience [22], it can be a favorable approach to conduct complicated experiments. Experiments like cognitive abilities assessments

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can require long-term observation or resources to conduct the experiment in specific environments. This can be done more efficiently with VR due to the variability with choices to create your environment. VR holds great potential for enhancing cognitive ability assessments, especially in the fields of attention, problem solving, and executive function [19]. Similarly, VR has been found that it is an effective approach in evaluating cognitive performance [15]. It has been proven to be useful in clinical settings as well, for cognitive behavioral therapy (CBT) [23]. Surveys showed that it can be equally effective as in-person exposure therapy. Therefore, using VR as a tool to observe the reaction of individuals is invaluable to conduct experiments and measure results.

Stress confronts individuals daily and is a pervasive phenomenon[28]. Psychological stress can have major impacts on functions such as cognitive development [10] and decision making [13]. Stress describes experiences that are emotionally or physiologically challenging[13, 23]. One important factor of stress involves outside stimuli and can have great impacts on a person's stress level and cognitive ability. The impact of daily stressors have not been studied as extensively as long-term stressors [12], but daily stress hassles in the physical environment is anything unusually unyielding, harsh, or uncomfortable, especially when the persons affected regard such conditions as destructive to their well being [12]. Benefits of stress research range from improving daily life to benefitting the wider society [26]. This makes it a beneficial area of research and poses opportunities for further computer science research.

Due to the fact that VR provides high quality result on cognitive assessment [15], we can seek to understand the influence of virtual environments on stress and cognitive ability. A major factor choice of environments in this experiment is color, which can impacts a participant's stress level and mood [11, 17]. Some colors can make people feel more stressed, while others can help them relax. Environments designed with soothing colors, such as greens and blues, can significantly lower stress levels, which can potentially improve cognitive functions like organization, memory, and attention [11]. Environments designed with stress-inducing colors, such as red, cannot only increase stress levels but could also lower the efficiency of cognitive processes involved in organizing and sorting tasks. This contrast highlights the fundamental psychological principles behind how different environments influence behavior and the management of stress.

As a result, combining body-based and computer-based methods can help explore a person's stress levels, influenced by the environment with different colors. The study is made realistic and immersive by the use of head movement as a technique of interaction in these virtual reality environments. This approach also provides a concrete way of measuring the effects of environmental changes on stress levels and organizational ability. Heart rate variability (HRV), galvanic skin response (GSR), and electroencephalography (EEG) is important in detecting stress [25], highlighting the role of non-invasive methods for real-time measurement. This supports the objective of utilizing head movement and heart rates, especially with heart rates being useful for indicating stress levels.

2 RELATED WORKS

2.1 Cognitive Ability and Stress

Stressful scenarios can have a significant impact on cognitive function, whether that be positively or negatively. High stress environments might have negative effects on a person's function, which can influence their performance on tasks by lowering their cognitive ability.

General cognitive ability, often referred to as 'general intelligence', includes a variety of correlated abilities such as spatial and verbal abilities, information processing speed, and memory [16, 20]. Our experiment is based on a participants ability to complete an organizational task, which includes core cognitive functions such as these. Looking

at the effects of stress on cognitive ability can show how a stressful environment may impact a participant's success level in the organization task.

Researchers have found that individuals in harsh and unpredictable environments tend to be more present-oriented [5]. The observation shows a decrease in cognitive performance under various environmental stressors. That is, stressful environments make people feel uncomfortable, which give them a sense of uncertainty, resulting in reduced cognitive functions. Additionally, stress has been associated with a greater risk of error-related brain functioning [21]. One study done that related consequences of stress on cognitive performance using HRV (heart rate variability) the frontal alpha activity in the electroencephalogram (EEG) showed that stress is induced primarily due to focus, motor-coordination and memory related tasks [21]. Extensive research has shown objective measures of stress as body functions, such as heart rate, are affected when a person experiences stress [28] and are reliable things to measure to gauge a person's stress level. Effects on cognitive performance is important to consider regarding our experiment because it relied on focus and motor-coordination from the participant. The participant is using their hands in the VR simulation to grab and sort objects, which requires both focus and motor-coordination. This process is explained in more detail in the methodology section of this paper.

However, some papers show an improvement in cognitive function under stressful environments. An example of this is shown in childhood cognitive ability. Some specific stressors, such as maternal health and social interaction can have impacts on a child's development and cognitive ability. [16]. Growing up in a stressful environment can sometimes enhance cognitive functions, such as shifting (efficiently switching between different tasks) in adulthood [14]. Stress is not always a negative force, as it is necessary for learning, and can be a positive aspect when it is under control[3].

Therefore, stress can sometimes be a beneficial way for people to learn, or it can hinder this process due to the state of mental or emotional strain and pressure[3, 28]. These studies show the complexity of the relationship between stress and cognitive abilities. Stressful environments can either impair or enhance cognitive functions depending on types of stressors. It highlights the importance of understanding how stress impacts cognitive processes in different ways. Recognizing and understanding the complicated effects of stressful environments on cognition is crucial for educational, occupational, and health-related interventions

2.2 Environment Impact on Stress Level

Environment can be described in multiple ways, but we are focusing on the definition of environment being immediate and physical. A special kind of transaction or relationship between two systems, person and environment[18]. In relating stress and environment, stress being the sources in the environment (the input or stimulus) and the person is on one hand, while the stress response or reaction on the other.

The environment, both psychosocial and physical, has significant implications for behavior and affect [18]. Environmental conditions operate directly in the causation of stress reactions[12]. Two important features of the environment include colors and sounds.

Color is an essential part of our surroundings and can have specific effects on emotional state. including anxiety and stress levels [11]. Of the elements comprising the spatial environment, environmental color exerts the most potent influence, stimulating human vision [17]. This is important for our experiment because we relied on the changing of colors for the second virtual reality (VR) environment. In one study, Wilson [30] found that red induces higher arousal levels than greens. In addition, red is found to cause avoidance behaviour when subjects perceived it as a warning cue in performance related task, drawing away attention [7].

Another factor of environment includes sounds and noise. There is a direct effect between sounds and emotional well being [29]. In addition to direct pathways between the ear canal and brain functionality, there are a variety of indirect connections from the inner ear to the brain centers that control basic physiological, emotional and behavioral responses of the body [29]. Previous works have shown when noise is associated with fear, found unnecessary, or the participant dislikes other parts of the environment, annoyance is heightened [2]. Physiological changes produced by noise are typically associated with stress responses [2].

Noises and colors in a persons environment can cause the participant to feel discomfort and increase stress levels. On the other hand, environmental factors have been proven to decrease stress levels. In a research study using virtual reality (VR) technology, the researchers show that natural environments have been largely employed in virtual environments aimed to promote stress reduction, for their widely studied and established ability to regulate stress and promote well-being [6].

An issue to be aware of is that many environmental events that are stressful may be neutral or even positive for some persons and negative for others [12]. It is important to understand the importance of environment on stress level. Whether that increases or decreases a participants well-being and state of stress.

3 RESEARCH METHODS

For this study, we created immersive environments using virtual reality (VR) to have participants complete an organizational task within that environment. We used Godot as our game engine with its powerful animation system and built-in coding language called GDScript. The three environments we made include a constant forest environment, a visually-altered forest environment, and an auditory-altered forest environment.

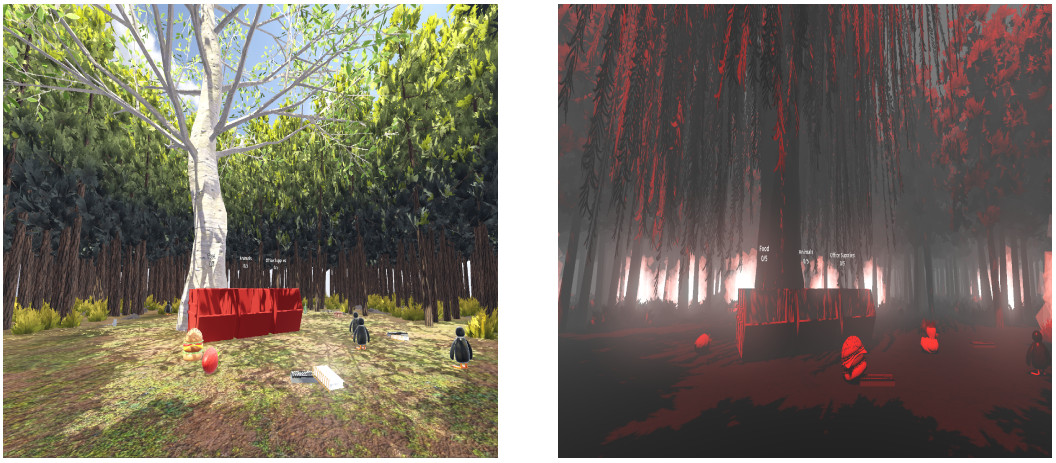
Using VR to create the environments allowed us to create different noises and visuals specific for what we were testing. We had the ability to add fire, change the tone color of trees, and add specific noises that contradict the scene. Stress is commonly elicited through internal or external stimuli[28].

3.1 Virtual Reality Environments

Constant Forest Scene 1a is the first environment that participants witnessed and navigated in the experiment. This scene utilized relaxing colors, such as greens and soft light. It also included soft forest sounds of rustling leaves and light breeze. This scene was meant to act as the constant variable, with the next two scenes altering either the visuals or sounds. Our goal for this scene was to make it a relaxing environment. Several lines of research have shown the potential of nature experience in positively affecting well-being and reducing stress[6].

Red Forest Scene 1b is the second scene which featured the same sounds as the first forest, of breeze and rustling leaves, but was altered visually. This forest scene utilizes the color red to induce a feeling of unease and stress visually. As explained further in the related works section of this paper, red has been proven to induce heightened feelings or stress levels.

Spooky Forest Scene is the third and final environment scene used for this experiment. This scene looked the same as *Constant Forest* 1a, but featured stressful/scary noises and music. We used noise found on a disturbing music YouTube video [31]. This scene focused on utilizing the knowledge of unnecessary noises causing stress [2] and directly impacting performance on tasks demanding concentration [29].



(a) Constant Forest (b) Red Forest

Fig. 1. Virtual reality environments used for the experiment. Scene one (a). Scene two (b).

3.2 Measurements

Stress is commonly assessed using subjective and objective measures. [28]. The subjective measure we used was heart rate through a heart rate tracker on the participant's wrist. Short-term stress responses include cardiovascular reactions such as heart rate [2, 4] which makes heart rate an important piece to consider regarding stress level. Under acute stress, people may experience symptoms such as sweaty palms or increased heart rate [27]. HRV (heart rate variability) is also shown to be an indicator for time related pressures or emotional strain on a person[21] as well as negative impacts on mood stability [8]. Kim et al. [9] showed that HRV parameters highly correlated with stress in their literature review of the HRV parameters and stress.

It is important to keep in mind the individual participants in this experiment and their personal responses. It is not always simple to decide whether stress arises from an environmental or external condition or from an internal personal disposition, or from both [18]. To best gauge each individual's experience, we provided a survey before each trial and after each trial. Questions on this survey were focused on asking about the participants experience with gaming, their current stress level, and how noises and colors impact them. This is how we measured the subjective effects of each environment scene and its impact on the participant's stress level. Traditionally, subjective methods determine the stress level of a person through questionnaires and answers rated on a stress scale. These measures are known to provide highly reliable data reflective of perceived emotions [28]. We also provided a stress scale for the participants before the experiment and after each scene.

3.3 Procedure

We recruited thirteen participants for this experiment and completed a within-subjects design. Each participant completed an organizational task in each of the three scenes. Nine of the participants answered they have had experience with VR in the pre-experiment questionnaire.

Upon arrival, the participant was asked to fill out a consent form, a questionnaire, and rate their current stress level on a scale of one to ten. The questionnaire asked about their experience with video games and VR, as well as their sensitivity to sounds and colors.

The participant then began the first VR scene *Constant Forest* 1a and organizational task. The organizational task consisted of three categories of objects to sort. These three object categories were animals, food items, and office supply items. Each category of items contained three different types of each item and these were randomly generated on the ground within the scene. Total dispersed items equalled five of each, which was fifteen items the participant had to pick up and sort. The middle of the scene contained three red bins with text above each bin for the chosen category and a count of how many out of five items they had successfully placed. Please see Figure 1 of the VR scenes which feature the bins. The participant's task was to navigate the scene, pick up the item, then bring it to the correct bin to sort. The participant was timed in seconds until all items were placed within the correct bin.

Next, the participant rated their current stress level, then continued to scene two, *Red Forest Scene* 1b for the same organizational task. The participant repeated this for the third scene as well.

4 RESULTS

Out of thirteen participants, ten rated the second scene, *Red Forest Scene* 1b, as the scene that elevated their stress level the most. This is shown in the below Figure 3a. One person said they didn't notice a difference, while all other participants noted some difference. This correlates with the stress level ratings shown in Figure 3b. The mean stress levels of all participants after scene two was 33% higher than the mean stress levels after scene one and 20% higher than mean stress levels after scene three.

We ran an ANOVA (analysis of variance) on both the average heart rate of each participant in each scene, and on the time it took each participant to complete the scenes. The mean heart rate for scene two was 90.38 bpm, which is 4.85% higher than the average heart rate observed for scene one, which was 86 bpm. ANOVA was conducted to compare the completion times between scene one, scene two, and scene three. The ANOVA reveals the difference was statistically significant

$$(F_{2,12} = 8.263, p < .005)$$

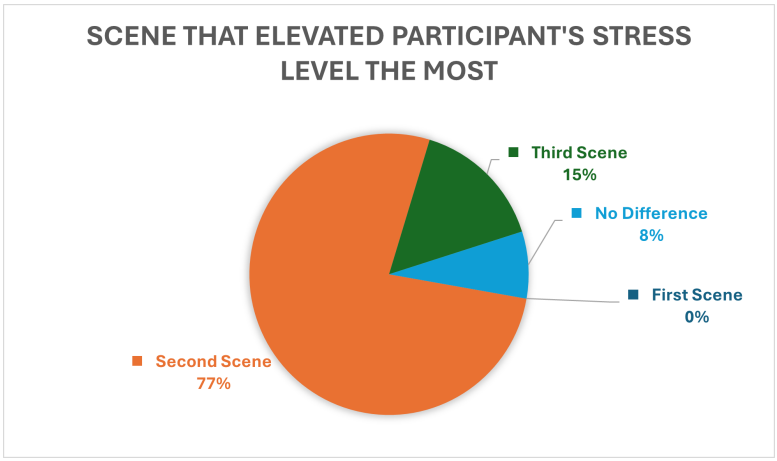
These results are shown in Figure 2.

ANOVA Table for Average Heart Rates (bpm)

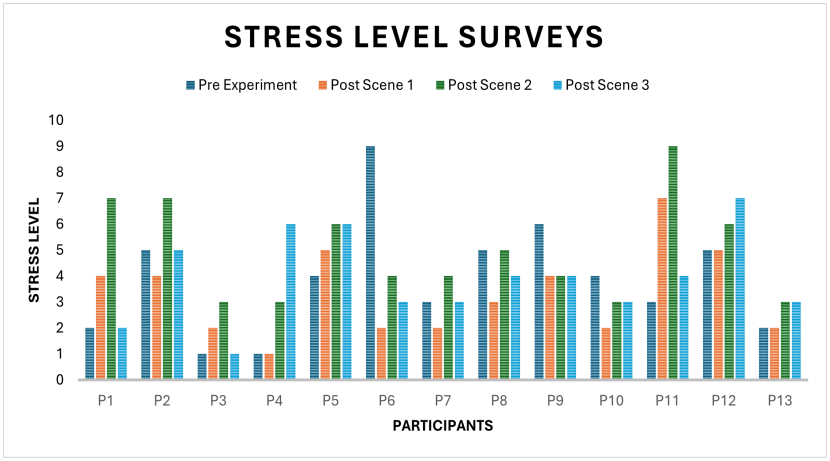
	DF	Sum of Squares	Mean Square	F-Value	P-Value
Participant	12	2959.692	246.641		
Scene	2	204.974	102.487	8.263	0.0019
Scene * Participant	24	297.692	12.404		

Fig. 2. ANOVA Table for Heart Rate Data

The mean time completion rate for scene three was 153.62 s, which is 72.9% faster than the average time completion rate observed for scene one, and 92.8% faster than rates for scene two. The mean time completion rate was slowest for scene two at 296.15 s.



(a) Results for the post-experiment question of: Which scene did you find elevated your stress level the most?



(b) Results for stress level ratings.

Fig. 3. Statistical findings from the experiment surveys. Pie chart (a). Bar chart (b).

ANOVA was conducted to compare the completion times between scene one, scene two, and scene three. The ANOVA reveals the difference was statistically significant

$$(F_{2,12} = 9.211, p < .005)$$

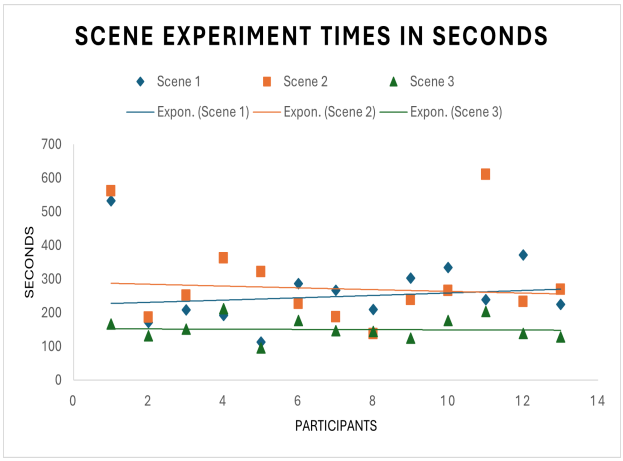
These results are shown in Figure 5 below.

4.1 Discussion

Our results show that participants found the second scene to be the most stressful. They also showed time completion rates dropped significantly after the second scene. Although the time completion rates show statistical significance, it's important to keep in mind the potential for learning bias. Since the participant completed the same task in each scene,

Participant	Scene Completion Time (s)		
	Scene 1	Scene 2	Scene 3
P1	532	561	167
P2	171	186	132
P3	209	251	151
P4	192	362	212
P5	113	322	96
P6	286	227	177
P7	267	188	147
P8	210	137	144
P9	303	239	124
P10	334	265	177
P11	239	610	204
P12	372	233	138
P13	225	269	128

(a) Participant's Completion Time (s)



(b) Trend lines for participant time completion rate in seconds.

Fig. 4. Data (a). Scatter plot with trend lines (b).

ANOVA Table for Scene Completion Time (s)

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Participant	12	196651.333	16387.611		
Scene	2	145478.923	72739.462	9.211	0.0011
Scene * Participant	24	189521.744	7896.739		

Fig. 5. ANOVA Table for Time Completion Rate in seconds

they may have picked up on the skill by the third scene. We didn't think this would have a major impact because it was a simple task and most of the participants had experience with virtual reality.

Another limitation to consider is experimenter demands. This could have unknowingly influenced the participant acting a different way in the environments that weren't the constant environment. They could have expected we were looking for a stress response and then their organizational skills were impacted due to experimenter demand. Carry-over between scenarios can create patterns that would not exist in an isolated situation, or over-sensitivity to changes in parameters can develop that leads to observed differences where they would not otherwise exist. [1] we vary the order of the scenarios presented to each individual in the within study, but their elicited value under the second scenario is always biased by their exposure to the first. The authors suggest that in a within-design, subjects feel more compelled to differentiate their answers by observing both scenarios at once and having to contrast them.

5 CONCLUSION

Understanding stress and its impact on cognitive abilities is an important relationship to understand for bettering people's lives. VR gives us an opportunity to explore research in cases where it might be difficult to replicate in real life. By taking advantage of VR as a platform to test the stress response derived from different virtual environments, this study revealed the association between various environmental factors, like color and sound, and someone's stress levels.

Our research indicated statistical significance between environmental stress and effects on cognitive performance and physical stress responses. The health consequences of stress and the negative impact on cognitive ability shows that the environment around us has a direct impact on us. To combat this, we could take this research among others to reduce stress by noticing how colors and sounds in our environments impact our functioning ability. Future research should explore this cognitive impact in other types of scenes to explore what combination of factors has the most impact. Future studies could also explore the difference between VR stressful environments and real world stressful environments to see if there is a strong correlation between the two, or if they impact a person differently.

REFERENCES

[1] Gary Charness, Uri Gneezy, and Michael A. Kuhn. 2012. Experimental methods: Between-subject and within-subject design. *Journal of Economic Behavior & Organization* 81, 1 (2012), 1–8. https://doi.org/10.1016/j.jebo.2011.08.009

[2] Sheldon Cohen, Gary W. Evans, Daniel Stokols, and David S. Krantz. 2013. *Behavior, Health, and Environmental Stress.* Springer Science & Business Media.

[3] Alfredo Córdova, Alberto Caballero-García, Franchek Drobnic, Enrique Roche, and David C. Noriega. 2023. Influence of Stress and Emotions in the Learning Process: The Example of COVID-19 on University Students: A Narrative Review. *Healthcare (Basel, Switzerland)* (2023).

[4] Suelen Moraes de Lorenzo, Vitor Engrácia Valenti, Luiz Carlos de Abreu, Celso Ferreira, and Carlos B. M. Monteiro. 2013. Integrative aspects of the relationship between stress and heart rate variability. *ABCS Health Sciences* 38 (2013). https://api.semanticscholar.org/CorpusID:59936847

[5] Willem E Frankenhuis, Karthik Panchanathan, and Daniel Nettle. 2016. Cognition in harsh and unpredictable environments. *Current Opinion in Psychology* 7 (2016), 76–80. https://doi.org/10.1016/j.copsyc.2015.08.011

[6] Simone Grassini. 2022. The use of VR natural environments for the reduction of stress: an overview on current research and future prospective. In *Proceedings of the 33rd European Conference on Cognitive Ergonomics* (, Kaiserslautern, Germany,) *(ECCE '22)*. Association for Computing Machinery, New York, NY, USA, Article 4, 5 pages. https://doi.org/10.1145/3552327.3552336

[7] Nurlelawati Ab. Jalil, Rodzyah Mohd Yunus, and Normahdiah S. Said. 2012. Environmental colour impact upon human behaviour: A Review. *Procedia - Social and Behavioral Sciences* 35 (2012), 54–62. https://doi.org/10.1016/j.sbspro.2012.02.062

[8] Derek W. Johnston and Pavlos Anastasiades. 1990. The relationship between heart rate and mood in real life. *Journal of Psychosomatic Research* 34, 1 (1990), 21–27. https://doi.org/10.1016/0022-3999(90)90004-N

[9] Hye-Geum Kim, Eunjin Cheon, Daiseg Bai, Young Lee, and Bon Hoon Koo. 2018. Stress and Heart Rate Variability: A Meta-Analysis and Review of the Literature. *Psychiatry investigation* 15 (02 2018). https://doi.org/10.30773/pi.2017.08.17

[10] Pilyoung Kim, Gary W. Evans, Michael Angstadt, S. Shaun Ho, Chandra S. Sripada, James E. Swain, Israel Liberzon, and K. Luan Phan. 2013. Effects of childhood poverty and chronic stress on emotion regulatory brain function in adulthood. *Proceedings of the National Academy of Sciences* 110, 46 (Oct 2013), 18442–18447. https://doi.org/10.1073/pnas.1308240110

[11] Teresa M. Kutchma. 2003. The Effects of Room Color on Stress Perception: Red versus Green Environments. *Journal of Undergraduate Research at Minnesota State University, Mankato* 3 (2003). https://doi.org/10.56816/2378-6949.1172

[12] Richard S. Lazarus and Judith Blackfield Cohen. 1977. *Environmental Stress.* Springer US, Boston, MA, 89–127. https://doi.org/10.1007/978-1-4684-0808-9_3

[13] Mara Mather and Nichole R. Lighthall. 2012. Risk and reward are processed differently in decisions made under stress. *Current Directions in Psychological Science* 21, 1 (Jan 2012), 36–41. https://doi.org/10.1177/0963721411429452

[14] Chiraag Mittal, Vladas Griskevicius, Jeffry A Simpson, Sooyeon Sung, and Ethan S Young. 2015. Cognitive adaptations to stressful environments: When childhood adversity enhances adult executive function. *J Pers Soc Psychol* (2015). https://doi.org/doi:10.1037/pspi0000028

[15] Alexandra Negut. 2014. Cognitive assessment and rehabilitation in virtual reality: theoretical review and practical implications. *Romanian Journal of Applied Psychology* 16, 1 (2014). https://www.ingentaconnect.com/content/doaj/14548062/2014/00000016/00000001/art00001

[16] Frances M Nilsen, Jazmin Ruiz, and Nicolle S. Tulve. 2020. A Meta-Analysis of Stressors from the Total Environment Associated with Children's General Cognitive Ability. *International Journal of Environmental Research and Public Health* 17 (2020). https://api.semanticscholar.org/CorpusID:220976996

[17] Jiyoung Oh, Haengwoo Lee, and Heykyung Park. 2021. Effects on Heart Rate Variability of Stress Level Responses to the Properties of Indoor Environmental Colors: A Preliminary Study. *International Journal of Environmental Research and Public Health* 18, 17 (2021). https://doi.org/10.3390/ijerph18179136

[18] Katharine R. Parkes. 1986. Coping in stressful episodes: The role of individual differences, environmental factors, and situational characteristics. *Journal of Personality and Social Psychology* (1986). https://doi.org/10.1037/0022-3514.51.6.1277

[19] Thomas D. Parsons, Susan McPherson, and Victoria Interrante. 2013. Enhancing neurocognitive assessment using immersive virtual reality. *2013 1st Workshop on Virtual and Augmented Assistive Technology (VAAT)* (2013). https://doi.org/10.1109/VAAT.2013.6786190

[20] Robert Plomin. 1999. Genetics and general cognitive ability. *Nature* (1999).

[21] Sachin Prathaban, Vishal Sisodia, and Sadasivan Puthusserypady. 2019. Consequence of Stress on Cognitive Performance: An EEG and HRV Study. In *TENCON 2019 - 2019 IEEE Region 10 Conference (TENCON)*. 1969–1974. https://doi.org/10.1109/TENCON.2019.8929634

[22] Weixin Ren, Yang Gu, and Yuan Tao. 2022. Research on the Methods of VR Technology to Reduce the Stress of College Students: A Case-study of Virtual Aquarium. (2022). https://doi.org/10.1145/3488466.3488481

[23] Justas Salkevicius, Robertas Damaševičius, Rytis Maskeliunas, and Ilona Laukiene. 2019. Anxiety Level Recognition for Virtual Reality Therapy System Using Physiological Signals. *Electronics* 8 (09 2019). https://doi.org/10.3390/electronics8091039

[24] Maria T. Schultheis and Ronald R. Mourant. 2001. Virtual Reality and Driving: The Road to Better Assessment for Cognitively Impaired Populations. *Presence: Teleoperators and Virtual Environments* 10, 4 (2001), 431–439. https://dl.acm.org/doi/10.1162/1054746011470271

[25] Nandita Sharma and Tom Gedeon. 2012. Objective measures, sensors and computational techniques for stress recognition and classification: a survey. *Comput Methods Programs Biomed* (2012). https://doi.org/10.1016/j.cmpb.2012.07.003

[26] Nandita Sharma and Tom Gedeon. 2013. Modeling stress recognition in typical virtual environments. In *2013 7th International Conference on Pervasive Computing Technologies for Healthcare and Workshops*. 17–24. https://doi.org/10.4108/icst.pervasivehealth.2013.252011

[27] Sasha L. Sommerfeldt, Stacey M. Schaefer, Markus Brauer, Carol D. Ryff, and Richard J. Davidson. 2019. Individual Differences in the Association Between Subjective Stress and Heart Rate Are Related to Psychological and Physical Well-Being. *Psychological Science* 30, 7 (2019), 1016–1029. https://doi.org/10.1177/0956797619849555 PMID: 31188735.

[28] Kuan Tao, Yuhan Huang, Yanfei Shen, and Lixin Sun. 2022. Automated Stress Recognition Using Supervised Learning Classifiers by Interactive Virtual Reality Scenes. *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 30 (2022), 2060–2066. https://doi.org/10.1109/TNSRE.2022.3192571

[29] J C Westman and J R Walters. 1981. Noise and stress: a comprehensive approach. *Environmental Health Perspectives* 41 (1981), 291–309. https://doi.org/10.1289/ehp.8141291

[30] Glenn Wilson. 1966. Arousal properties of red versus green. *Perceptual and Motor Skills* 23 (12 1966), 947–949. https://doi.org/10.2466/pms.1966.23.3.947

[31] YouTube 2010. https://www.youtube.com/watch?v=trELfLtJwDQ